NEVIS - 2

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Joint ONR - AEC Program
Office of Naval Research Contract
Contract N6-ori-110 Task No. 1

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R-78

ABSORPTION OF NEGATIVE PIONS IN DEUTERIUM: PARITY OF THE PION

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CU-66-54-ONR-110-1-Physics

Absorption of Negative Pions in Deuterium: Parity of the Pion*

W. Chinowsky and J. Steinberger

Columbia University, New York, New York

May, 1954

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* This research was supported by the joint program of the Office of Naval Research and the Atomic Energy Commission.

ABSTRACT

The reaction $\pi^- + D \rightarrow 2N$ has been observed by detecting the two neutrons in coincidence with slow negative mesons incident on a liquid deuterium target. The observed angular correlation of the two neutrons confirms the identification of the process. The process is therefore not forbidden, and this fact may be used to establish the odd relative parity of the pion and the nucleon.

I. INTRODUCTION

It was first pointed out by Feretti[1] that the capture

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[1] Ferreti, B., Report on Conference on Low Temperature and Fundamental Particles, 75 (Cambridge, Massachusetts, (1946)

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in deuterium of negative mesons at rest might furnish a means of distinguishing between scalar and pseudo scalar pions. The reaction

$$\pi^- + D \rightarrow 2N \qquad (1)$$

is forbidden for scalar mesons in S-states since requirements of angular momentum and parity conservation and the Pauli principle can not simultaneously be satisfied. The argument is independent of the theoretical model for the process. If the reaction is observed, then to rule out scalar parity for the pion, it is only necessary to show that the reaction proceeds indeed from an S-state. Brueckner, Serber and Watson[2] have shown, using the measured cross

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[2] Brueckner, Serber and Watson, Phys. Rev., <u>81</u>, 575 (1951)

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section for the process $\pi^+ + D \rightarrow 2P$, extrapolated to lower energy, that capture from the excited states of the meson-deuteron atom does not compete favorably with electromagnetic

deexcitation. At most, one in thirty mesons are expected to be captured before reaching the ground state. Therefore, if more than one-thirtieth of the stopped mesons are captured according to process (1), the meson cannot be scalar. Since it has already been shown that the pion has zero spin,[3,4]

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[3] Durbin, Loar and Steinberger, Phys. Rev., 83, 646 (1951)
[4] Clark, Roberts and Wilson, Phys. Rev., 83, 649 (1951)

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the pion is then pseudo scalar.

The only previous evidence for reaction (1) is furnished by the experiments of Panofsky, Aamodt and Hadley.[5] In these

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[5] Panofsky, Aamodt and Hadley, Phys. Rev., 81, 565 (1951)

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experiments measurements were made on the energy spectra of γ-rays from hydrogen and deuterium gases at 3000 lb/sq.in. pressure and 78°k in which mesons had come to rest. All reactions in hydrogen give γ-rays, either directly or through π^{0} decay. The γ-ray yield from deuterium was lower and left 70 percent of the capture processes unaccounted for. This was interpreted to mean that 70 percent of the captures proceed through reaction (1).

In view of the important consequences of this result, we have performed an experiment in which the two neutrons are observed in coincidence and in coincidence with incident mesons some of which come to rest in a container of liquid deuterium.

This provides a direct observation of the process (1) and confirms the conclusions of Panofsky et al.

II. EXPERIMENTAL ARRANGEMENT

Negative mesons produced at the internal target of the Columbia University 390 Mev Cyclotron are collimated in a channel of the 8 foot iron shielding wall and further analyzed by a double focusing magnet and the beam defining counters #1 and #2. (See Fig. 1.) Counter #1 is a liquid scintillator 4 1/2 inches in diameter and 5/8 inches thick; counter #2 is a stilbene crystal 2 1/4 inches horizontally, 2 3/4 inches vertically, and 1/8 inch in thickness. Between counters #1 and #2 a 2 gm/cm^2 carbon absorber is inserted, with 5 gm/cm^2 of LiH and 2.7 gm/cm^2 of polyethylene between counter #2 and the deuterium target. The absorber thickness is chosen to maximize the number of mesons which stop in the deuterium; the type of material to minimize coulomb scattering, consistent with convenience.

The hydrogen target previously described[6] is used here

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[6] Bodansky, Sachs and Steinberger, Phys. Rev., 93, 1367 (1954)

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with liquid deuterium in the scattering chamber. The only modification required is the insertion of a plug to prevent communication between the hydrogen and deuterium reservoirs. The D_2 intake is connected to the gaseous-deuterium filling

system shown in fig. 2. Before liquefaction the pressure of the gas in the 115 gallon reservoir is 21 lb/sq.in. On admission to the target the gas is cooled by passing successively through copper coils in the liquid nitrogen and hydrogen reservoirs. When equilibrium is reached, approximately 1/2 liter of liquid has accumulated and the pressure of the deuterium system is 5 lb/sq.in. The liquid deuterium in the reservoir can be admitted to the target cup and returned in the manner previously described. At the conclusion of the experiment, the hydrogen is allowed to evaporate and the deuterium returns to the gas reservoir.

Counters #3 and #4, the neutron detectors, are liquid scintillators 2 1/2 inches in diameter and 2 inches thick along the direction of motion of the neutrons. Counters 5 a, b, c, and d are plastic scintillators 4 1/2 inches in diameter and 1/2 inch thick. The center of each neutron counter is 5 3/8 inches from the center of the target cup. The six counters of the detection system have a common axis passing through the center of the target cup.

An "event" constitutes a coincidence 1234 in anti-coincidence with the parallel connection of the set of four counters #5. (See Fig. 3.) The neutrons are detected by means of stars or proton recoils made in #3 and #4. The discriminator on the 34 coincidence is adjusted so that pulses in #3 and #4 are rejected if the energy loss due to

ionization is less than roughly 10 mev. Charged particles are rejected in counters #5c and #5a. Low energy γ-rays are rejected by the pulse height requirement and high energy γ-rays converted in #3 and #4 are rejected in counters #5b and #5d. The system is specific for the detection of N-N coincidences with neutron energy greater than approximately 10-20 Mev. The effeciency for detection can be estimated from information on the N-P cross-section[7] and star form-

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7 Hadley, Kelly, Leith, Segre, Wiegand and York, Phys.Rev., 75, 351 (1949)

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ation in carbon.[8] These experimental results yield a prob-

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8 Kellogg, D. A., Phys. Rev., 90, 224 (1953)

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ability $\epsilon_n = .065 \pm .015$ for the formation by 70 Mev neutrons, of charged secondaries with energy sufficient to register a 34 coincidence.

III. EXPERIMENTAL RESULTS

A. The Process $\pi^- + D \rightarrow 2N + \gamma$*

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* The reaction $\pi^- + D \rightarrow 2N + \pi^0 \rightarrow 2N + 2\gamma$ is improbable.[5] In an experiment which will be reported at a later time we have shown that this process occurs in less

than 0.1 percent of the cases of absorption.

We have used the γ-rays of this reaction in order: 1) to determine the thickness of the absorber in the incident beam which maximizes the number of mesons which come to rest in the target, 2) permit an estimate to be made of the ratio R of the non-radiative to radiative capture rates, $R = \frac{(\pi^- + D \rightarrow 2N)}{(\pi^- + D \rightarrow 2N + \gamma)}$. To detect the γ-rays, counter #3 is replaced by an absorber, 1.8 mg/cm^2 of polyethylene, with a converter of 7 gm/cm^2 of Pb directly in front of counter 5a. The circuits are arranged to record coincidences 12 and 125a5b. The product of solid angle and efficiency for this arrangement is $\epsilon_\gamma \Omega_\gamma = 0.20$. The 125a5b rate as a function of the absorber thickness is shown in Fig. 4. The absorber used in the following experiments is 9.7 gm/cm^2. For this absorber thickness the γ-ray counting rate is

$$CR_{2N + \gamma} = \frac{125a5b}{12} = (488 \pm 5) \times 10^{-6}.$$

B. N-N Coincidences

The results of the search for N-N coincidences with the geometry of Fig. 1 and the electronic arrangement of Fig. 3 are given in Table 1. The observed 2N rate $CR_{2N} = \frac{(1234)-5}{12} = (.62 \pm .19) \times 10^{-6}$. The ratio R is $\frac{CR_{2N}}{CR_{2N + \gamma}} \times \frac{\epsilon_\gamma}{(\epsilon_N)^2} \times \frac{\Omega_\gamma/4\pi}{\Omega_N/2\pi\ g}$. g is a geometrical factor; it is the probability that one of the two neutrons traverse counter

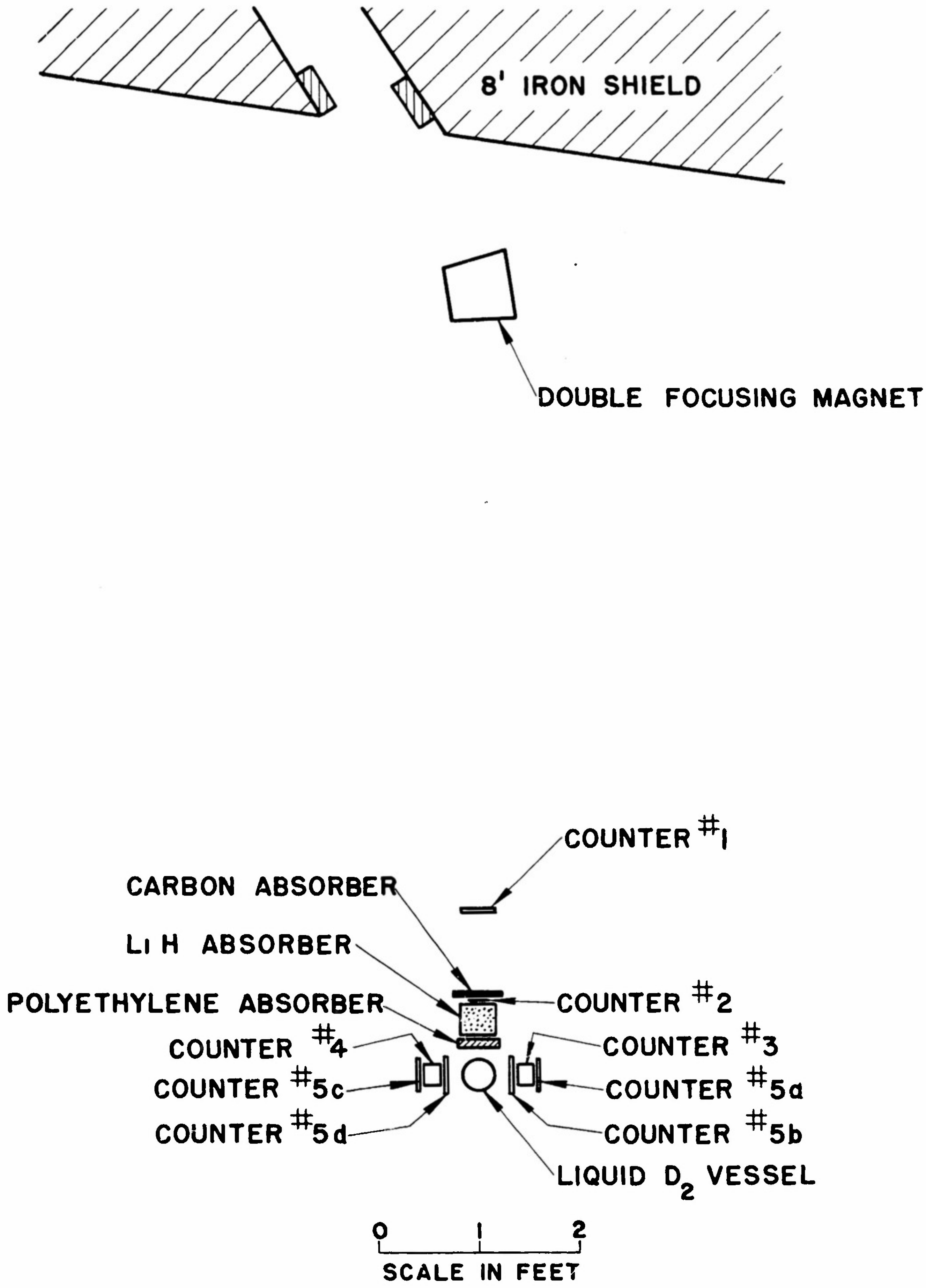
#3 if it is known that the other has traversed counter #4 and that the two neutrons were emitted at 180° to each other. The quantity g was computed numerically to be 0.12. With the values $\epsilon_\gamma \Omega_\gamma = 0.20$, $\epsilon_N = .065 \pm .015$ and $\Omega_N = 0.17$, then $R = 1.5 \pm 0.8$. This is quite similar to the value $R = 2.4 \pm 0.5$ obtained by Panofsky et al from a comparison of the γ-ray yields in hydrogen and deuterium. The discrepancy is within the experimental uncertainties.

C. N-N Angular Correlation

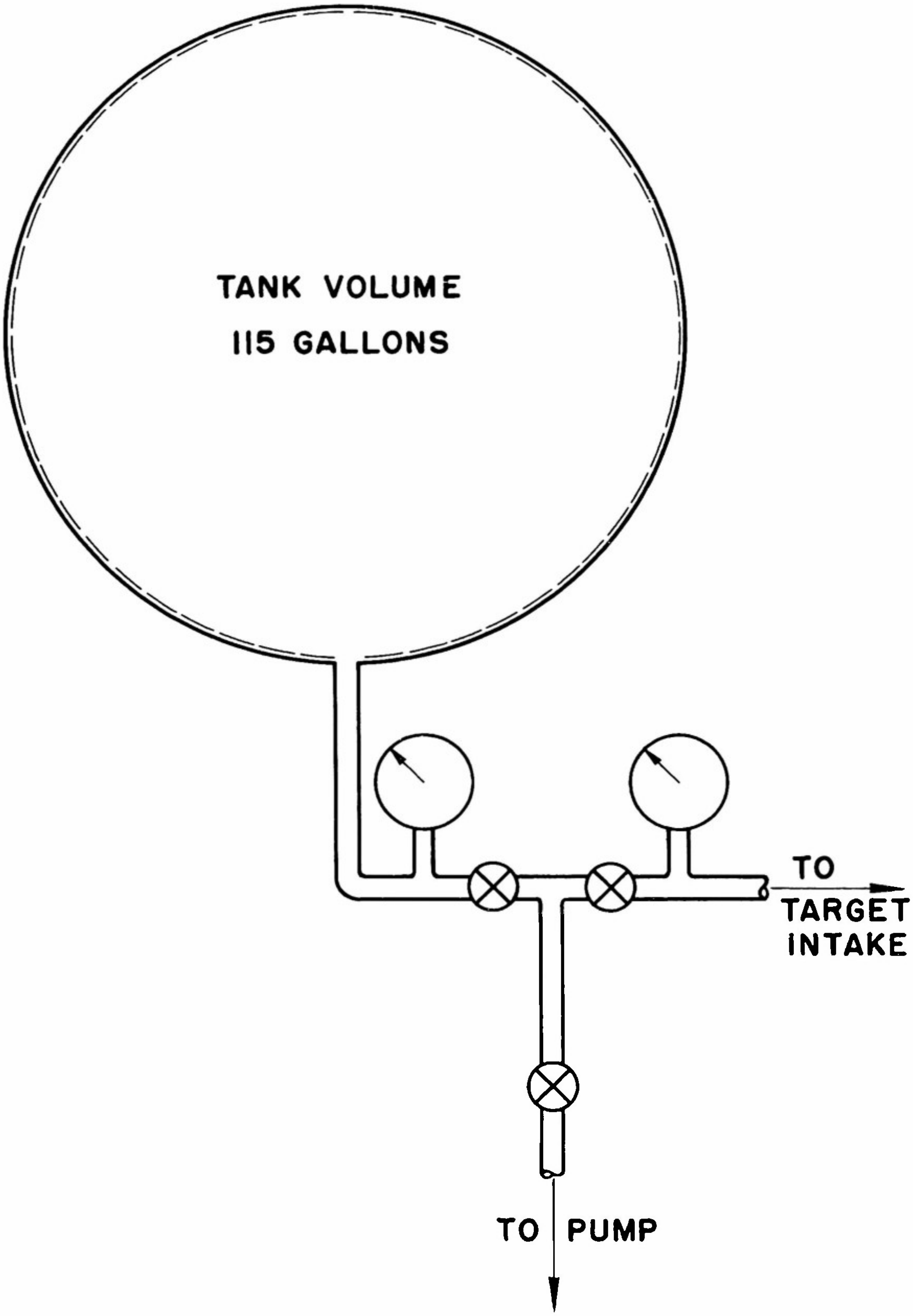
To test the identification of the observed events we have measured the coincidence rate as a function of the angle subtended by the two neutron detectors at the target. This was, however, physically impossible with the arrangement of Fig. 1. It was necessary to sacrifice the anticoincidence counters 5a and 5c to obtain the required mobility without reducing the counting rate to an impossible value. The new geometry is shown in Fig. 5. The additional absorber serves to make the system insensitive to low energy charged particles and the remaining anticoincidence counters reject high energy γ-rays. The results are shown in Fig. 6. The theoretical curve represents the response of the detection system to particles emerging with equal probability from the various volume elements of the deuterium and at 180° to each other. The consistency of the experimental points with the calculated function confirms the identification of the events as N-N coincidences.

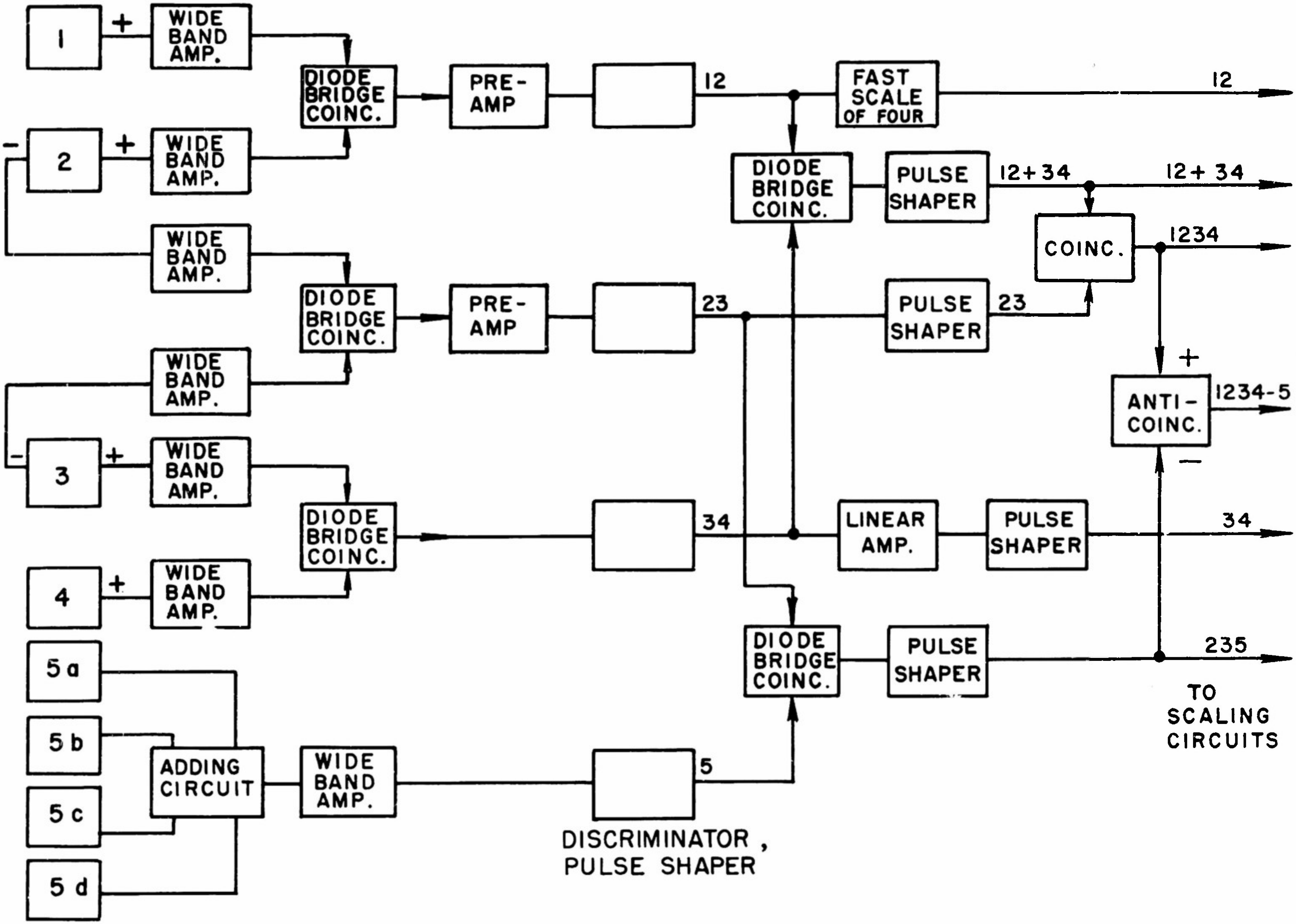
Table 1. N-N Coincidences Observed with Geometry of Fig. 1. Rates are per 10^6 Incident Mesons As Measured in 12 Coincidence.

	Counts with D_2 in Cup	Counts with Cup Empty	Net Due to D_2
1234	1.02 ± .19	.08 ± .1	.94 ± .20
1234-5	.70 ± .16	.08 ± .1	.62 ± .19

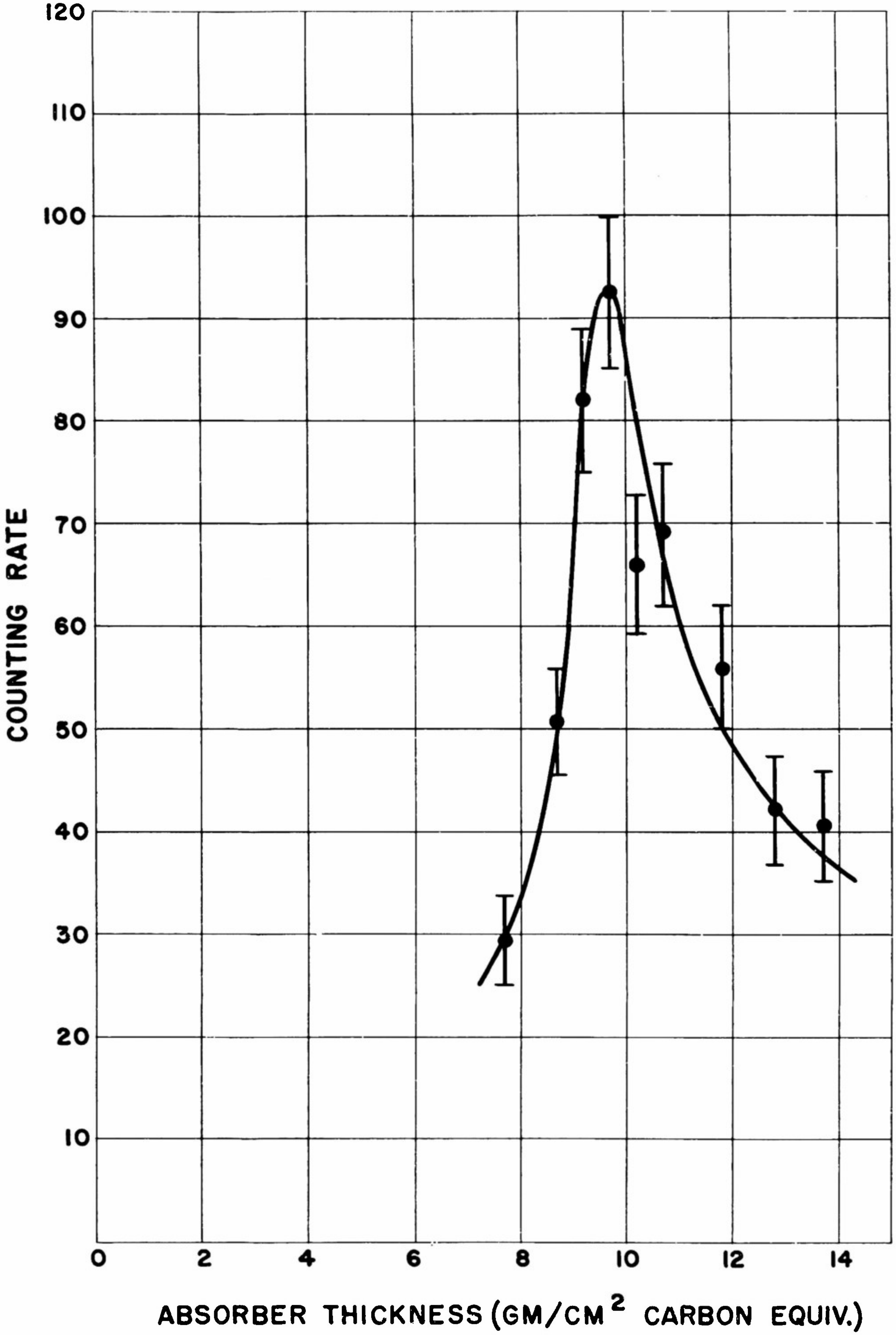


8' IRON SHIELD
DOUBLE FOCUSING MAGNET
COUNTER #1
CARBON ABSORBER
Li H ABSORBER
POLYETHYLENE ABSORBER
COUNTER #2
COUNTER #4
COUNTER #3
COUNTER #5c
COUNTER #5a
COUNTER #5d
COUNTER #5b
LIQUID D_2 VESSEL
0
1
2
SCALE IN FEET

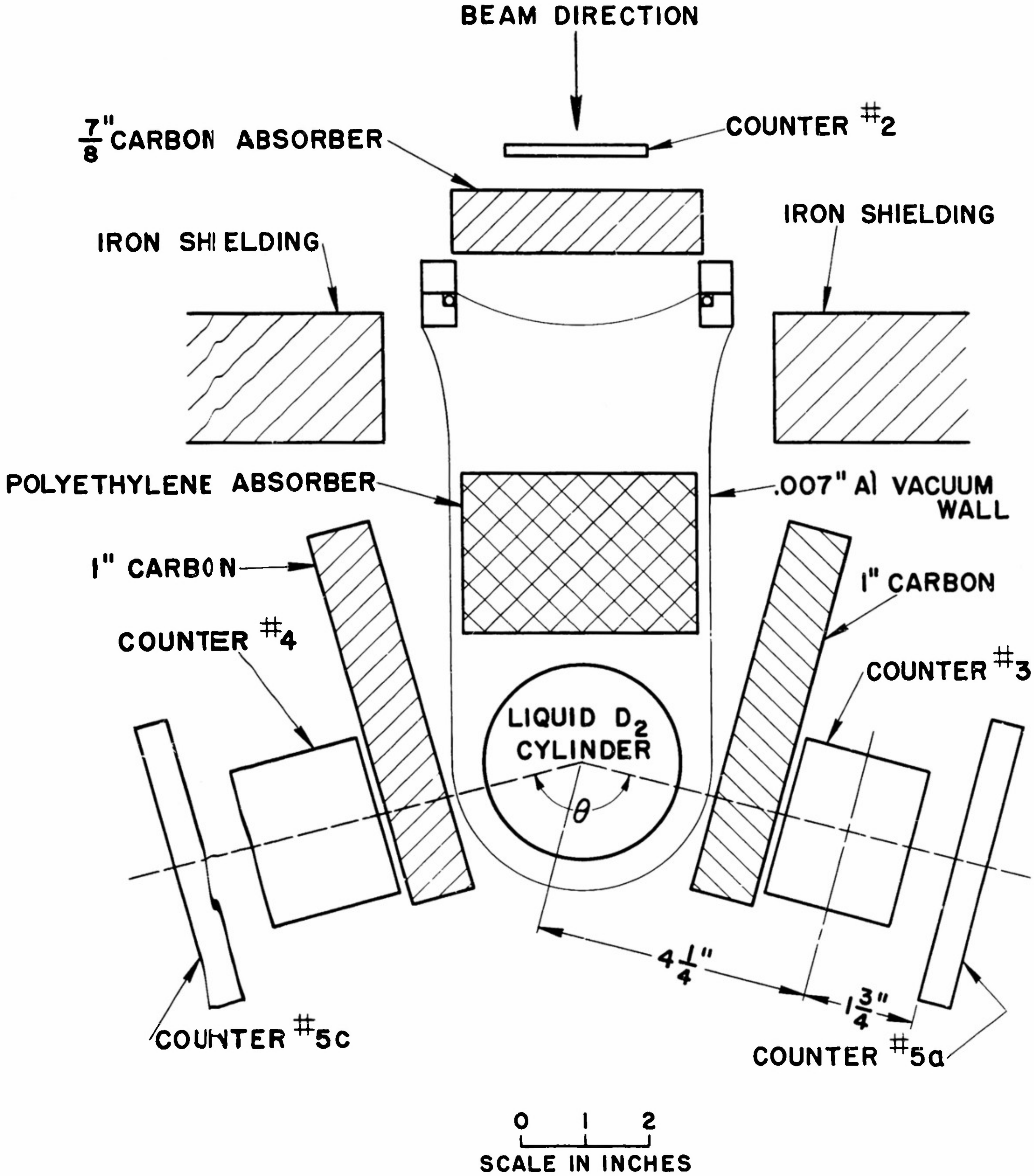

TANK VOLUME
115 GALLONS
TO
TARGET
INTAKE
TO PUMP



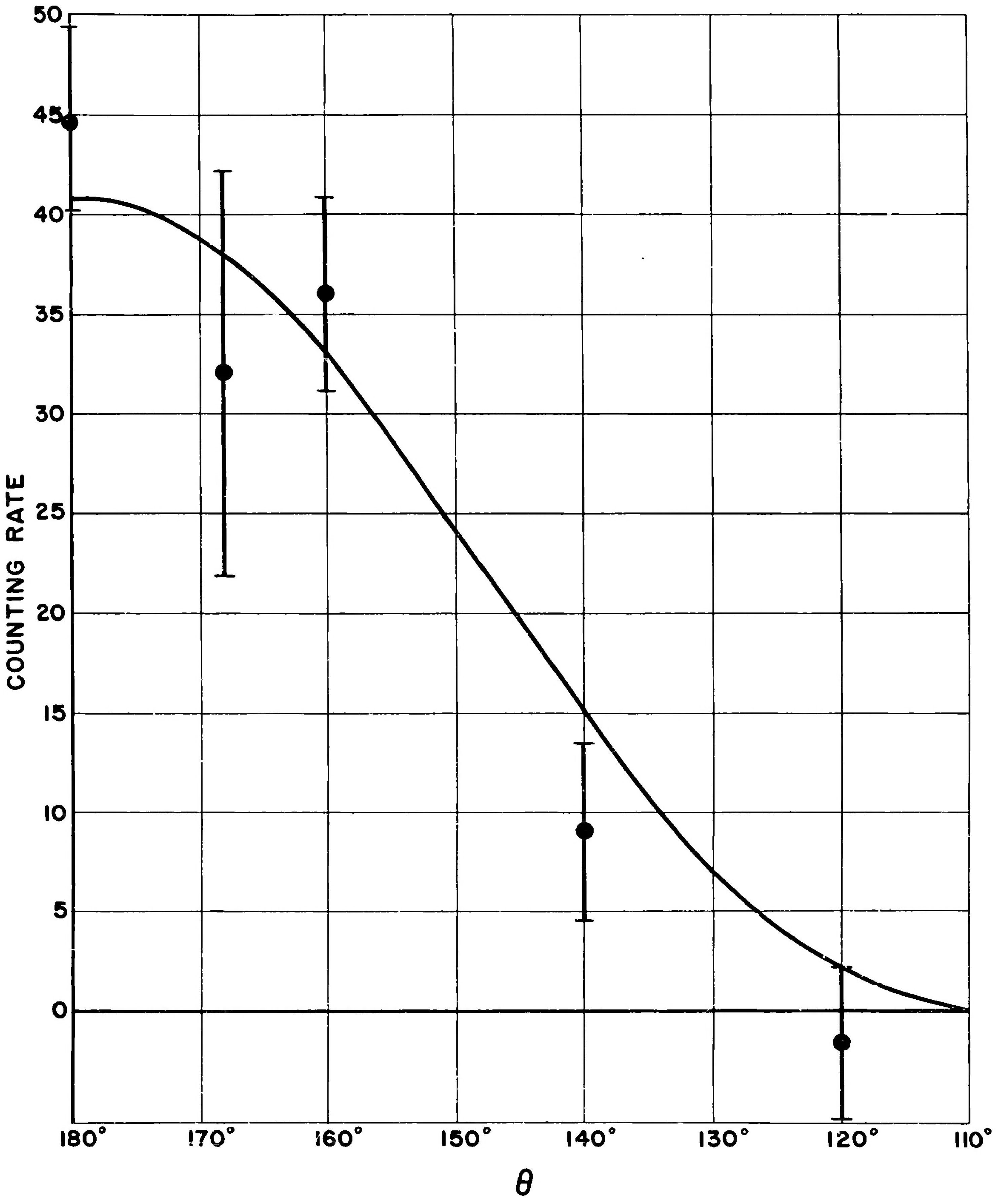
1
2
3
4
5 a
5 b
5 c
5 d
+
-
WIDE BAND AMP.
DIODE BRIDGE COINC.
PRE-AMP
ADDING CIRCUIT
12
23
34
5
DISCRIMINATOR , PULSE SHAPER
FAST SCALE OF FOUR
PULSE SHAPER
LINEAR AMP.
COINC.
ANTI-COINC.
12+ 34
1234
1234-5
235
TO SCALING CIRCUITS



120
110
100
90
80
70
60
50
40
30
20
10
COUNTING RATE
0
2
4
6
8
10
12
14
ABSORBER THICKNESS (GM/CM 2 CARBON EQUIV.)



BEAM DIRECTION
COUNTER #2
7/8" CARBON ABSORBER
IRON SHIELDING
IRON SHIELDING
POLYETHYLENE ABSORBER
.007" Al VACUUM WALL
1" CARBON
1" CARBON
COUNTER #4
COUNTER #3
LIQUID D2 CYLINDER
θ
4 1/4"
1 3/4"
COUNTER #5c
COUNTER #5a
0 1 2
SCALE IN INCHES



50
45
40
35
30
25
20
15
10
5
0
COUNTING RATE
180°
170°
160°
150°
140°
130°
120°
110°
θ